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Materials Joining and Forming: A Summary of the Literature

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INTRODUCTION

The Center for Economic Development at the Levin College of Urban Affairs at Cleveland State University prepared this report for the Ohio Manufacturing Institute (OMI) at The Ohio State University. The objective of this study is to provide background analysis of the materials joining and forming industries for the OMI as they prepare a roadmap for the future and recommendations concerning these industries for the Ohio Development Services Agency (ODSA).[1] This report provides a literature review and summary of findings.

Literature was collected and reviewed from various sources on the materials joining and forming industries. Academic articles, reports, and studies were collated and analyzed from databases, internet searches, and publications. The goal of this report is to provide a clear context of the state, national, and international conversation on the materials joining and forming industries, as well as to delineate opportunities and challenges as it relates to these industries.

Materials joining and forming are considered two distinct industries with separate manufacturing purposes. However, we reviewed the materials joining and forming literature as one process. Therefore, we consider materials joining and forming two separate industries under one literature review within this analysis. We will refer to them as the materials joining and forming industries; and will most commonly refer to them as "joining and forming."

[1] This report was prepared with financial support from the State of Ohio. All contents of this report reflect the views of the Grantee and do not reflect the views of ODSA or that of the State of Ohio.

DEFINITION

The methods of joining and forming are two of the most fundamental processes in engineering; they are vital in the manufacturing process that changes the shape of materials and combines parts (of the same or different materials).[2] This can be done for materials of all types. Joining and forming are two of the oldest manufacturing processes being used for micro and macro component fabrication.

Joining and forming are two distinct, yet related, processes. Joining is an assembly process with the goal of fabricating large or complex parts, while material forming is defined as "elastic and plastic deformation of materials" in order to create a desired shape (p. vii).[3] Virtually all industries require some kind of materials joining and forming. The most prominent industries that rely on these processes are automotive, aerospace, oil and gas, mining, and consumer products.

During joining and forming processes, the material and metallurgical properties of parts undergo considerable change, which presents an opportunity for researchers to study these processes through experiments and computational means.[4] Although joining and forming are among the most mature of industrial processes, the emergence of new materials has created a great opportunity for research and advancement.

JOINING

Joining is the ability to fuse two or more objects together. There are many types of joining: [5]

- ***Joining-by-forming*** processes are widely used to permanently join two or more metals through plastic deformation. Considerable literature exists about the joining-by-forming process discussing/covering ways to deal with different materials (e.g., magnesium alloys).[6]
- ***Roll bonding*** is a joining process in which two or more metal strips or plates are bonded by a flat rolling process.
- ***Friction welding*** is a process in which two metals are joined by pressure.
- ***Butt welding*** is a type of joining where two ends of a round sheet and a metal strip are joined by heat to form the basis for a wheel rim.
- ***Explosive welding*** is a type of joining which involves a chemical reaction.
- ***Rotation friction drilling riveting (RFDR)*** is a joining process in which a semi-tubular rivet with a grip rod and a rivet cap rotate at high speed and generates heat allowing the rivet to be to be drilled into the sheets under reduced force.[7]
- ***Friction stir welding (FSW)*** is a solid state joining process that combines frictional and deformational heating in order to join materials together.[8]

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[2] (2011, February 28). Manufacturing Technology: Forming and Joining – Forging Ahead. *Engineer*. 38

[3] Narayanan, R. G. (2015). *Advances in material joining and forming*. Springer.

[4] Ibid.

[5] Bambach, M., Pietryga, M., Miklowet, A., & Hirt, G. A finite element framework for the evolution of bond strength in joining-by-forming processes. *Journal of Materials Processing Technology*. 214, 2156-2168.

[6] Neugebauer, R., Mauermann, R., Dietrich, S., & Kraus, C., (2007). A new technology for the joining by forming of magnesium alloys. *Production Engineering Research and Development*. 1, 65-70.

[7] Han, G., Wang, M., Liu, Z., & Wang, P.C., (2013). A New Joining Process for Magnesium Alloys: Rotation Friction Drilling Riveting. *Journal of Manufacturing Science and Engineering*. 135, 1-9

[8] Marré, M., Ruhstorfer, M., Tekkaya, A., E., Zaeh, M., F., (2009). Manufacturing of Lightweight Frame Structures by Innovating Joining by Forming Processes. *International Journal of Material Form*. 1, 307–310.

FORMING

Forming is a general term used for a wide variety of manufacturing processes involving a large group of materials. In this report, we differentiate between two major types of materials that are shaped and formed: 1) metal forming; and 2) plastics and composite materials forming.

Metal forming: Generally refers to plastically deforming the metal to shape it into a desired geometry. Plastic deformation (as opposed to elastic deformation) means that the material will not recover its shape after the stress is released. Temperature is a very significant factor in metal forming because properties of metal can change due to an increase in temperature. Therefore, it is important to know both the behavior of the particular material in different temperatures and the requirements or characteristics of the new part in order to determine at what temperature metal forming should be conducted. There are three basic temperature ranges at which the metal can be formed:

1) Cold working (room temperature or a little above);
2) Warm working (above room temperature but below the recrystallization temperature of metal); and
3) Hot working (higher than the recrystallization temperature of metal).

Forming at each of these temperature ranges has its own advantages and drawbacks. In addition, qualities that may be undesirable to one process or one type of product can be desirable for another. For instance, to build a strong part with excellent surface finish, a cold forming process is appropriate. To build a part with high ductility, on the other hand, a hot process is a better choice. It is also possible to use a combination of forming temperatures to produce a desired end result. For example, hot working may be used first to achieve a significant shape change, followed by cold working to finish the shape change, further strengthening the part, and giving it a good surface finish.

In terms of processes, metal forming can generally be classified into two types:

1) Bulk deformation processes, characterized by a low surface area-to-volume ratio of the part - Bulk deformation can be done through: a) rolling (use of rolls); b) forging (use of dies to compress); c) extrusion (forcing metal through a die opening); and d) drawing (pulling metal through a die opening).

2) Sheet metal working processes, characterized by a high surface area-to-volume ratio - Sheet metal working can be done through: a) shearing (cutting of the work piece or punching holes), bending (bending about a certain axis), and c) deep drawing (forcing a flat piece of metal into a die cavity to produce a shape, such as a mug).[9]

Plastics and composite materials' forming and shaping: Plastics are usually shipped to plants as pellets, granules or powders. Thermoplastics are then melted prior to shaping because these polymers can be shaped when heated and regain original hardness and strength when cooled. Thermosets, on the other hand, are liquid plastics that cure into final form and are permanently set when heated. Increasingly, manufacturing plants are using recycled plastics, which generally produce lower quality products. There are ten different types of forming and shaping processes for plastics and composite materials:

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[9] Metal Forming. (n.d.). Retrieved May 15, 2015, from http://thelibraryofmanufacturing.com/forming_basics.html

1) ***Extrusion-***used for continuous and complex cross sections that are uniformly solid or hollow. Extrusion is characterized by high production rates, relatively low tooling costs, and wide tolerances.
2) ***Injection molding-***used for complex shapes of different sizes. Injection molding is often characterized by very high production rates, expensive tooling, and good dimensional accuracy.
3) ***Structure foam molding-***used for large parts with high stiffness-to-weight ratio. Production rates of this process are low, but this tooling is less costly than injection molding.
4) ***Blow molding-***used for hollow, thin-walled parts and bottles. Its tooling costs are relatively low, and its production rates are high.
5) ***Rotational molding***-used for large, hollow parts with a relatively simple shape. Rotational molding is characterized by both relatively low tooling costs and production rates.
6) ***Thermoforming-***used for shallow or relatively deep cavities. It involves low tooling costs and has medium production rates.
7) **Compression molding-**used for parts similar to impression-die forging. It often involves costly tooling, and has medium production rates.
8) **Transfer molding**-used for more complex parts than compression molding. It also yields higher production rates, but still involves high tooling costs and some scrap loss.
9) ***Casting***-used for simple or intricate shapes made with rigid or flexible low-cost molds. Casting often yields low production rates.
10) **Processing of composite materials**-is often characterized by long cycle times and expensive operation. Its tooling costs are highly dependent on the process.[10]

STATE OF THE INDUSTRY

Since the joining and forming industries rely heavily on production and metal working occupations, it is no surprise that there is concern about potential workforce issues. Businesses are struggling to find employees with the skills needed to compete in the global economy, and to help them economic development intermediaries' work with companies to increase their competitiveness. More than ever, there is a plea for solutions to the shortage of middle-skill employees. The Harvard Business Review states, "Shortages of workers for these types of jobs [middle-skilled] are already undermining U.S. competiveness and causing firms to shift their operations abroad." (p.83).[11] In order for the U.S. to have a sustainable workforce, it must address the pipeline issue of middle-skilled jobs.

The Manufacturing Institute estimates that there are 600,000 open jobs due to the skills gap in the United States.[12] Moreover, these open positions affect companies' bottom line to the tune of $461,509 of output (a proxy for gross product) per employee.[13]

[10] Kalpakjian, & Schmid. (2010). Plastics and composite materials: Forming and shaping. Retrieved May 14, 2015, from http://www.engr.mun.ca/~adfisher/3941/Ch19_Plastics_Composites.pdf.
[11] Kochan, T., Finegold, D., & Osterman, P. (2012, December). Who Can Fix the "Middle-Skills" Gap? Harvard Business Review, pp. 83-90.
[12] Manufacturing Institute (2015). The Economic Impact of the Skills Gap. Retrieved May 8, 2015 from http://www.themanufacturinginstitute.org/Research/Skills-Gap-in-Manufacturing/2011-Skills-Gap-Report/Economic-Impact/Economic-Impact.aspx
[13] Ibid.

LACK OF NATIONAL CONVERSATION

The overall lack of conversation within the joining and forming field is evident. The only industry planning documents are the 2002 American Welding Association Roadmap, and the NIST Roadmap that is currently underway. Other than that, there is a significant dearth of information regarding both of these industries. Unlike other manufacturing sectors, where consulting firms and private industry sources weigh in with white papers, literature on the joining and forming industries is disconcertingly quiet. There are two possible explanations for this lack of literature and conversation: 1) this is an older technology with an established literature, and/or 2) private industry looks to protect legally its intellectual property through legal channels and patents.

First, the lack of national literature on joining and forming could be attributed to the fact that this technology is older and has been used in manufacturing for decades. Although joining and forming are known as old manufacturing, this may be changing because of the introduction of new materials. New materials have been considered a "game changer" across the spectrum of manufacturing. New materials consist of a variety of mediums such as ceramics,[14] alloys (high-temperature, nickel-based, iron and cobalt-based), and stainless steels.[15] However, many of these new materials are difficult to work with. The demand to use new materials has increased in the automotive and aerospace industries due to component part innovation and a push for lightweighting of vehicles.

A second potential reason for the lack of literature in this area is that private industry is protecting their intellectual capital through intellectual property and/or trade secrets. Therefore, this material is not being shared with the greater public for comment and insight. This is why ongoing public-private conversations are important.

Although there is limited literature produced by or within the joining and forming industries, there is some conversation in the trade industry and academic publications. These publications provide information to industry experts on technical aspects of the industry (i.e. parts specifications, stress factors, new materials, etc.). However, there is no overarching trade publication that deals with issues within this field since joining and forming is segmented into the industries that it serves. Consequently, professionals in the automotive joining and forming industries would be more likely to find information in automotive trade publications instead of "joining trade publications."

One important distinction should be made in the national conversation: there is a difference in the lexicon used in the overall technical conversation and that within workforce development. Within the broader conversation, the terms "joining" and "forming" are used, while in the workforce arena "welding" and "career and technical education" are used and "welding" replaces "joining."

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[14] Srejith, P.S. & Ngoi, B.K.A (2001) Material removal mechanisms in precision machining of new materials. *International Journal of Machine Tools and Manufacture*, 41 (12), 1831-1843.

[15] National Technical Conference Indianapolis. Difficult to Machine Materials. Retrieved May 07, 2015, from https://www.pmpa.org/docs/default-source/technical-conference/difficult-to-machine-materials-intro.pdf?sfvrsn=0

AUTOMOTIVE LIGHTWEIGHTING

In 1975, the U.S. government established the Corporate Average Fuel Economy (CAFE) standards, which sought to reduce energy consumption by increasing the fuel economy of cars and trucks.[16] The CAFE standards ushered in an era of greater fuel efficiency in cars. The Environmental Protection Agency (EPA) and National Highway Transportation Safety Administration (NHTSA) issued new standards through 2025 for cars and light trucks that would slowly ratchet the fuel economy of cars from 35.5 MPG in 2016 to 54.5 MPG by 2025.[17]

In order to comply with this legislation, automakers looked for several ways to increase fuel efficiency, one of which was lightweighting vehicles. Lightweighting is a process, which substitutes lighter materials for standard steel products.[18] It is estimated that the average vehicle will be 400 pounds lighter by 2025.[19] The conversation surrounding CAFE standards is important to the joining and forming industries considering that they use all of the materials contained within this conversation – both older materials (such as steel) and new materials (such as polymers).

Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability (USDRIVE), a partnership among U.S. Department of Energy (DOE), Chrysler, Ford Motor Company, General Motors, five energy companies (BP America, Chevron Corporation, Phillips 66 Company, ExxonMobil Corporation, and Shell Oil Products US) and two utilities (Southern California Edison and DTE Energy), examined the future of vehicle efficiency. One of the USDRIVE research teams studied a roadmap for materials involved in this initiative.[20] As the industry continues to meet the goals set by the CAFE standards, additional R&D is needed to overcome some of the technical and engineering specifications.

NIST NATIONAL ROADMAP

The Edison Welding Institute (EWI) and its EWI Forming Center were awarded almost $500,000 to develop a Comprehensive Advanced Joining and Forming Technology Roadmap for the National Institute of Standards and Technology (NIST) under the Advanced Manufacturing Technology Consortium Program (AMTech).[21] EWI is an engineering and technology organization involved in advanced materials joining and allied manufacturing technologies in Columbus, Ohio.[22] This roadmap will identify R&D goals, workforce needs, technology development, and manufacturing capabilities of the industry.[23]

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16 National Highway Transportation Safety Administration (n.d.) CAFE - Fuel Economy. Retrieved April 23, 2015 from http://www.nhtsa.gov/fuel-economy

17 U.S. Environmental Protection Agency, "EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017-2025 Cars and Light Trucks," http://www.epa.gov/otaq/climate/documents/420f12051.pdf.

18 The National Institute of Standards and Technology (2015, March 27) The NIST Center for Automotive Lightweighting Mission. Retrieved on April 23, 2015 from http://www.nist.gov/lightweighting/

19 Agarwal, R. (2013, May 7). Technology advancements enabling vehicle lightweighting. Aerospace, Metals Industries

20 USDRIVE. (2015, February) Materials Technical Team Roadmap. Retrieved on May 29, 2015 from http://energy.gov/sites/prod/files/2015/04/f21/MTT%20Roadmap%20UPDATE%20Apprvd%2003-11-15.pdf.

21 National Institute of Standards and Technology (2014, May 6) Development of a Comprehensive Advanced Joining and Forming Technology Roadmap. Retrieved May 27, 2015 from http://www.nist.gov/amo/70nanb14h050.cfm

22 EWI. (2015). Company. Retrieved May 27, 2015 from http://ewi.org/about/

23 National Institute of Standards and Technology (2014, May 6) Development of a Comprehensive Advanced Joining and Forming Technology Roadmap. Retrieved May 27, 2015 from http://www.nist.gov/amo/70nanb14h050.cfm

Challenge & Opportunity

The lack of conversation on joining and forming can be considered both a challenge and an opportunity. The opportunity is that the lack of information means there is very little bad press to counteract. The Manufacturing Institute has pursued the "Dream It. Do It." campaign in an effort to overcome the negative stigma that a career in manufacturing is a dirty, low-wage job.[24] A lack of information about this segment of manufacturing may make it easier to recruit workers and circulate positive information. In addition, there seems to be a re-focus on how to make manufacturing "hip." Lincoln Electric recently launched a quarterly publication called *ARC Magazine* dedicated to celebrating welding, metalworking, and its lifestyle, with an inaugural cover that displays a young woman wearing a bandana, flexing her bicep – proving this isn't your father's manufacturing.[25] However, the challenge for the joining and forming industries lies in catching up to the other segments of manufacturing that have already produced a significant amount of literature which take part in the national conversation. Other technologies have already captured the audience and attention spans of the media, consumers at-large, and politicians who control science and technology budgets.

INTERNATIONAL CONVERSATION

International conversation regarding joining and forming of materials has primarily focused on reducing the weight of materials, as well as the costs of lightweight materials supply, forming components, joining and manufacturing. Additionally, a particular emphasis has been put on environmentally friendly materials' forming, joining and machining. The International Journal of Materials Forming and Machining Processes, for example, publishes peer reviewed journal articles from across the globe on research and development in forming materials and machining processes. Published journal articles cover virtually all formable materials, such as metals, polymers, ceramics, composites, biomaterials, nanomaterials, and others. Furthermore, the journal promotes development of environmentally friendly technologies in the field of materials forming and machining.[26]

In Europe, the need for improving research in the field of materials' of joining and forming was recognized in the early 90s—when a significant initiative named NUPHYMAT (i.e. Numerical and Physical Study of Material Forming Processes to the Commission of the European Community) was launched. Through the initiative, a collaborative project was defined for 13 prestigious laboratories across Europe covering a wide range of scientific topics regarding metal, polymers, and composite materials' of joining and forming. Later, additional laboratories from Eastern Europe also got involved. This collaborative laboratory effort played a major role in creating the European Scientific Association for Material Forming (ESAFORM) in 1997. ESAFORM has contributed to the development of a multi-disciplinary approach to material forming and various heat treatment processes as well as the introduction of advanced scientific methods for solving industrial problems.[27]

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[24] Manufacturing Institute (2015). Inspiring Youth with Dream It. Do It. Retrieved May 26, 2015 from http://www.themanufacturinginstitute.org/Image/Dream-It-Do-It/Dream-It-Do-It.aspx

[25] Suttell, S. (2015, June 2) Gordon Gund among billionaires pledging to commit fortunes to philanthropic causes. *Crain's Cleveland*. Retrieved June 2, 2015 from http://www.crainscleveland.com/article/20150602/BLOGS03/150609939/gordon-gund-among-billionaires-pledging-to-commit-fortunes-to

[26] http://www.igi-global.com/journal/international-journal-materials-forming-machining/69666

[27] Chinesta, F., & Cueto, E. (Eds.). (2007). Advances in material forming: Esaform 10 years on. Paris: Springer.

In the international arena, several road-mapping efforts have also been taken that primarily focus on identifying industry needs, investing in research and development, identifying and enhancing funding opportunities for technology development, improving the environmental footprint of material of joining and forming processes, and workforce development (including vocational education and training, distance learning, and life-long learning) and consortium development.

STATE ROADMAPS AND CONVERSATIONS

Advanced joining and forming has been considered by several states as an important technology area for capturing a competitive advantage in advanced manufacturing. Whereas much of the focus of states in this area has been on workforce development efforts, an emphasis has also been placed on creating an innovation ecosystem. Major state level discussions in the area of advanced joining and forming can be summarized in one of the categories below.

WORKFORCE DEVELOPMENT

As a part of their workforce development efforts, states have taken several approaches.

- **Identified critical workforce challenges.** Identification of workforce challenges is an important step towards developing an appropriate workforce development system. The critical workforce challenges at the state level may or may not resemble national level trends. For instance, at the national level, a gap exists between the industry demand for skilled welders and the supply pipeline.[28] Yet, the type and intensity of this problem may differ from place to place, highlighting the importance of this step. The North Carolina Commission on Workforce Development, for instance, has not only identified key workforce challenges at the state level but also has differentiated between challenges specific to metropolitan areas versus rural areas.[29]
- **Designed a call for action.** Once workforce challenges have been identified, an action plan must be designed to address specific challenges. This involves developing a framework for setting policies that can help alleviate or eliminate current needs while building the state's economic future. The states of Texas[30] and North Dakota,[31] for example, have taken a demand- or market-driven approach to create a workforce development system. This means that businesses and industries have access to appropriate pools of talent, while job seekers have access to services that provide them with the necessary skills. Often, a market-driven workforce development system also involves:

[28] Vistos, R. J. State of the welding industry report: Executive summary. Weld-Ed National Center for Welding Education and Training. Retrieved May 01, 2015, from (https://www.weld-ed.org/NR/rdonlyres/363B5036-3FB6-4631-B0DE-30B91EB82B88/0/welded_excutive_summ.pdf
[29] The North Carolina Commission on Workforce Development. (2011). State of the North Carolina workforce 2011-2020. Retrieved May 05, 2015, from http://www.nccommerce.com/Portals/11/Documents/Reports/2011%20SOTW%20Full%20Final%20Report%2052311%20909am.pdf
[30] Texas Workforce Commission. (2012). Workforce investment act title I-B annual report. Retrieved May 01, 2015, from, http://www.doleta.gov/performance/results/AnnualReports/PY2012/TXWIAAnnualReport2012.pdf
[31] Job Service North Dakota. (2013). Workforce investment act: PY 2013 annual report. Retrieved may 06, 2015, from http://www.doleta.gov/Performance/Results/AnnualReports/PY2013/ND-PY13_WIA_AnnualReport.pdf

- **Developing a collaborative response:** For the market-driven workforce development system to act as a hub for information exchange regarding jobs and skills, a collaborative response must be developed. For North Dakota this has meant a) supporting and investing in public-private partnerships to ensure the development of workers' skills based on industry needs; b) integrating education and training providers' efforts with business and public workforce activities in order to meet the skill demand by industries; and c) providing workers with "career ladder/lattice paths" to opportunities particularly in high-growth, high-demand occupations.[32] In an effort to respond collaboratively to workforce needs in Texas, a partnership has been built between Texas Workforce Commission and 28 Local Workforce Development Boards. For Texas, a collaborative response has involved incorporation of all potential customers, such as employers and job seekers, as well as workforce service providers, economic development agencies, colleges and universities, and other training providers.[33]

- **Facilitating Lifelong Learning.** Another key aspect of an appropriate response to workforce challenges is facilitation of lifelong learning. During their statewide focus groups, the North Carolina Commission on Workforce Development revealed that capability and willingness to engage in lifelong learning that will keep the workers' skills current was seen as critical by business representatives and other stakeholders.

- **Targeted Training Resources.** Because training resources are limited, some states have chosen to target training resources for supporting specific industries or businesses with the greatest potential contribution to the economy. High-growth industries, high-demand occupations, emerging industries or occupations, and those occupations that can potentially support the growth and development of an existing industry cluster are examples of categories typically considered for targeting resources. For example, California's Career Pathways Trust provides funding to support the development of curriculum that is "aligned to high-need, high-growth, or emerging regional economic sectors" (p.2).[34] Because advanced materials' of joining and forming is often classified as a high-need, high-growth technology area, several states have included it in their workforce development efforts. For instance, the Olympic Opportunity Internship program in the state of Washington targets high-demand occupations that pay a livable wage. As a part of the program, partnerships were built with local technical skill development centers to train youths in several targeted career fields, including welding.[35] Texas has also reported welders to be the highest-need occupations, followed by machinists and industrial-machinery mechanics. Because these occupations are high-need and pay above the state's median annual salary, in its 2014 report the Texas Comptroller of Public Accounts has recommended a focus on apprenticeship programs to ease worker shortages.[36]

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[32] Job Service North Dakota. (2013). Workforce investment act: PY 2013 annual report. Retrieved may 07, 2015, from http://www.doleta.gov/Performance/Results/AnnualReports/PY2013/ND-PY13_WIA_AnnualReport.pdf
[33] Texas Workforce Commission. (2012). Workforce investment act title I-B annual report. Retrieved May 01, 2015, from, http://www.doleta.gov/performance/results/AnnualReports/PY2012/TXWIAAnnualReport2012.pdf
[34] California Edge Coalition. (2013). Moving forward: Workforce development in California. Retrieved May 03, 201, from http://californiaedgecampaign.org/wp-content/uploads/2013/10/Moving-Forward-final-pdf.pdf
[35] Workforce Training and Education Coordinating Board, Washington State Employment Security Department and Washington's Workforce Development Councils. (2013). Workforce investment act title I-B: Annual report. Retrieved May 04, 2015, from http://wtb.wa.gov/Documents/WashingtonPY12WIATitleI-BAnnualReport.pdf
[36] Combs, S. (2013). Workforce: Capitalizing on our human assets. Retrieved May 01, 2015, from http://comptroller.texas.gov/specialrpt/workforce/96-1756.pdf

RESEARCH AND INNOVATION

Creating an environment that facilitates innovation and fostering research activities can result in direct economic benefits. Creating a platform for innovation and economic development requires linking research centers to industries and businesses. Across the nation, engineering research centers and industry/university cooperative research centers conduct research that can improve products, processes, and practices related to advanced materials' joining and forming. For example, in the energy, sustainability and infrastructure sector, four universities in the nation operate a "Center for Integrative Materials Joining Science for Energy Applications". These include Ohio State University, Colorado School of Mines, University of Wisconsin, and Lehigh University. In the advanced manufacturing and fabrication sector, in addition to Ohio State University, Virginia Commonwealth University also operates a center for precision forming.[37]

An example of related efforts to stimulate linkages between companies and researchers is led by a team at Northwestern University that supports development and implementation of advanced technologies and strategies in sheet metal forming. The University team along with firms and associations from diverse industries came together in an "integrated technology roadmapping effort" to address cross-cutting challenges, and monitor emerging new technologies as well as related skills training.[38]

[37] Peterson, T. W. Creating an innovation ecosystem. Retrieved May 10, 2015, from http://nsf.gov/attachments/115706/public/Innovation.pdf

[38] Advanced manufacturing processes laboratory. (n.d.). Roadmapping for Innovation in Sheet Metal Forming Workshop website. Retrieved May 07, 2015, from http://ampl.mech.northwestern.edu/research/current-research/nist-amtech.html